Agricultural Sciences, 2023, 14, 73-87
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Cassava Groundnut Intercropping: A Sustainable Land Management Practice for Increasing Crop Productivity and Organic Carbon Stock on Smallholder Farms

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How to cite this paper: Yila, K.M., Lebbie, M.S., Conteh, A.R., Kamara, M.S., Kamara, L.I. and Gboku, M.L.S. (2023) Cassava Groundnut Intercropping: A Sustainable Land Management Practice for Increasing Crop Productivity and Organic Carbon Stock on Smallholder Farms. *Agricultural Sciences*, **14**, 73-87.
https://doi.org/10.4236/as.2023.141006

Received: November 11, 2022
Accepted: January 28, 2023
Published: January 31, 2023

Abstract

Cassava-groundnut intercropping is not a common practice among smallholder farmers in Sierra Leone even though both crops are well suited for intercropping. On-farm trials were conducted in three locations (Bai Largor, Bassah, and Njala Kanima) in the Moyamba district during the 2021 cropping season to investigate the efficacy of cassava-groundnut intercropping for increasing crop productivity and soil organic carbon stock on smallholder farms in the Moyamba district, Southern Sierra Leone. The experimental design was a randomized complete block design in three replications with treatments of sole groundnut, sole cassava and cassava-groundnut intercropping. Data on the yield and yield components of cassava and groundnut were analysed using the PROC MIXED procedure of SAS 9.4 and means were compared using the standard error of difference (SED). The above-ground biomass, number of roots per plant, and fresh root yield of cassava were not significantly ($p > 0.05$) affected by the cassava-based cropping system. Averaged across locations, intercropping cassava with groundnut decreased the above-ground biomass, the number of roots per plant, and fresh root yield of cassava by 17%, 11%, and 17%, respectively. The above-ground biomass, number of pods per plant and fresh pod yield of groundnut were significantly ($p < 0.05$) affected by the groundnut-based cropping system. Averaged across locations, intercropping groundnut with cassava decreased the aboveground biomass, the number of pods per plant, and fresh pod yield of groundnut by 33%, 15%, and 31%, respectively. The cassava-groundnut intercropping treatment had favourable land equivalent ratios (LER > 1), the highest net revenue and benefit-cost ratio. The benefit-cost ratio was also favourable for the sole cassava (BCR > 1) but not favourable for the sole groundnut (BCR < 1). Averaged across locations, intercropping cassava with groundnut increased the benefit-cost ratio by 121% and 13% when compared to the sole groundnut and sole cassava. In the event of a 40% yield loss for the cassava and groundnut, the benefit-cost ratio was favourable (1.12) only for the cassava groundnut intercropping system. The net soil organic carbon stock was favourable only for the cassava-groundnut intercrop. Averaged across locations, the net soil organic carbon for the cassava-groundnut intercropping increased by 3.4% when compared to the baseline within one cropping cycle of the cassava (12 months). The results confirm that cassava-groundnut intercropping is a sustainable land management practice that could enhance crop productivity and soil organic carbon stock on smallholder farms.

Keywords

Benefit-Cost Ratio, Cassava-Groundnut Intercropping, Land Equivalent Ratio, Soil Organic Carbon, Sustainable Land Management

1. Introduction

Climate change is among the major challenges that need urgent attention in the 21st century. Sierra Leone is vulnerable to climate change and the climate-sensitive agriculture sector provides livelihoods for 75% of its population and contributes more than 50% of its Growth Domestic Product [1]. Since 1960, there has been evidence of increasing temperature, decreased and unpredictable rainfall and substantial climatic hazards such as floods, changed rainfall patterns, strong winds, thunderstorms and seasonal droughts [2]. In recent times, the gradual change in rainfall patterns and temperatures in the country has threatened the fragile agricultural system [3]. The lack of access to information, and technical or financial support are the major factors hindering the adaptation efforts that could help farmers invest in more climate-resilient agriculture [4]. Land degradation has important implications for climate change mitigation and adaptation. The consequences of continuing land degradation are severe, and of prime importance is the conversion of natural forest systems to cultivated croplands, which results in losses of between 20% and 50% of pre-cultivation soil organic carbon stocks in the surface meter of soil [5]. In addition, inappropriate practices (e.g. burning cropland and crop residues, repetitive tillage and excessive use of inorganic fertilizers without restoring soil organic matter) causing land degradation can further reduce soil organic carbon stocks in the soil [5]. The repercussions of these practices do not only affect the general welfare of individual farming households but also affect the local community, nation, region and the world at large.

In 2015, Sierra Leone has drafted its Intended Nationally Determined Contribution: one of the strategies to mitigate greenhouses gases (GHG) emissions is the "Adoption and application of climate-smart and conservation agriculture through best agricultural practices that enhance soil fertility and improve crop yield". Sustainable Land Management (SLM) strategies and practices can decrease GHG emissions and can enable farmers and communities to become more resilient to climate change [6]. Cassava-groundnut intercropping is one of the potential SLM practices for sustainable food and nutrition security for the most vulnerable populations while adapting and/or mitigating climate change.

Cassava is the second most important food and cash crop in Sierra Leone [7]. It is highly adaptable to climate change and drought resistance and has the potential to build long-term resilience to the uncertainties posed by variability in climate [8]. Farmers usually plant cassava as a sole crop on ridges or heaps in major cassava-producing areas in the country. The conventional tillage practices often result in soil degradation and emissions of carbon dioxide (CO_2) into the atmosphere [9]. Groundnut is a cash crop, has the potential to provide household incomes during critical periods (August to September) of food shortages in rural communities, and has the potential to increase SOC in the soil through the decomposition of its crop residues in addition to fixing nitrogen into the soil [10]. As a long-season and wide-spaced crop, the initial growth and development stage of cassava is slow and therefore permits intercropping with short-duration crops in a well-defined spatial crop arrangement and optimum density that will permit efficient use of plant growth factors. To this end, intercropping cassava with groundnut on flat land at a modified spatial arrangement could permit the effective use of growth factors for better and higher quality food production, on-farm income and climate change mitigation. In addition, intercropping with groundnut could lead to improved soil fertility, an increase in the amount of organic carbon storage in the soil through the decomposition of crop residue, reduction of nitrous oxide (N_2O) emissions through nitrogen fixation [10]. This study is therefore useful to generate evidence to support the efficacy of the cassava groundnut intercropping system as a sustainable management practice for increasing crop productivity and building farmers' resilience for climate change adaptation and mitigation. On this note, this study aims to evaluate the efficacy of cassava-groundnut intercropping systems as an innovation for climate change adaptation and mitigation by determining the:

1) Changes in soil organic carbon stocks as affected by cassava and groundnut-based cropping systems.

2) Effect of intercropping on the yield and yield components on cassava and groundnut.

3) Productivity of sole cassava, sole groundnut and cassava-groundnut intercropping systems.

2. Materials and Methods

2.1. Trial Sites

Three participatory on-farm trials were conducted during the 2021 cropping season in three locations in the Kori and Bagruwa chiefdoms in the Moyamba district. The trial sites were located at Bai Largor (N 08˚16.528', W 012˚08.942') in the Kori chiefdom and Bassah (N 07˚54.057', W 012˚27.212') and Njala Kanima (N 07˚54.941', W 012˚28.253') in the Bagruwa chiefdom.

2.2. Experimental Design and Treatments

The experimental design was a randomized complete block design in three replications. The treatments were sole groundnut, sole cassava and cassava-groundnut intercropping. The area for each treatment plot was 300 m^2 (30 m × 10 m).

2.3. Crop Establishment and Management

The land was brushed and the plant debris was cleared. The sole cassava and groundnut were planted on flat land at a plant spacing of 1 m × 0.75 m and 0.3 m × 0.2 m respectively. To reduce competition between the cassava and the groundnut in the cassava-groundnut intercrop, the spatial arrangement of the cassava was manipulated without compromising the plant densities used in the sole cropping systems, the plant spacing for the cassava in the intercropping system was 1.5 m × 0.5 m. The cassava and groundnut were planted simultaneously on the same land. Routine management practices were carried out throughout the trial period. The crop residue of the groundnut was returned to the cassava-groundnut intercrop plots after harvest.

2.4. Crop Measurements

Yield and yield components of groundnut

At full maturity (3 months after planting), the groundnut was harvested from a sample plot (200 m^2) in each replication to determine:

Above groundnut biomass yield **(*kg·ha*$^{-1}$):** The above-ground biomass cassava was calculated as follows:

$$\text{Above ground biomass} = \frac{\text{Weight of biomass from sample plot}\left(\text{kg}\right)\times 10000\ \text{m}^2}{200\ \text{m}^2\times 1\ \text{ha}} \tag{1}$$

***Average number of filled pods per plant*:** Twenty plants were randomly selected from the harvested plants and the number of filled pods for the twenty plants was counted. The average number of filled pods per plant was determined by dividing the total number of filled pods by twenty.

Fresh pod yield **(*kg·ha*$^{-1}$):** The weight of total filled pods harvested from the 200 m^2 sample plot was determined and used to calculate the fresh pod yield per hectare as follows:

$$\text{Fresh pod yield} = \frac{\text{Weight of filld pods harvested from sample plot}\left(\text{kg}\right)\times 10000\ \text{m}^2}{200\ \text{m}^2\times 1\ \text{ha}} \tag{2}$$

Yield and yield components of cassava

At full maturity (12 months after planting), the cassava was harvested from a sample plot (200 m^2) in each replication to determine:

Above cassava biomass yield **($kg \cdot ha^{-1}$):** The above-ground biomass cassava was calculated as follows:

$$\text{Above-ground biomass} = \frac{\text{Weight of biomass from sample plot}\left(\text{kg}\right) \times 10000\ \text{m}^2}{200\ \text{m}^2 \times 1\ \text{ha}} \quad (3)$$

***Average number of roots per plant*:** Twenty plants were randomly selected from the harvested plants and the number of filled pods for the twenty plants was counted. The average number of roots per plant was determined by dividing the total number of roots by twenty.

Fresh root yield **($kg \cdot ha^{-1}$):** The weight total of the fresh roots harvested from the 200 m^2 sample plot was determined and used to calculate the fresh pod yield per hectare as follows:

$$\text{Fresh pod yield} = \frac{\text{Weight of filld pods harvested from sample plot}\left(\text{kg}\right) \times 10000\ \text{m}^2}{200\ \text{m}^2 \times 1\ \text{ha}} \quad (4)$$

2.5. Productivity Measurements

Land use efficiency

The land equivalent ratio (LER) was used as a criterion for measuring the land-use efficiency of intercropping cassava with groundnut when compared with the sole crop of cassava and groundnut. The LER was calculated as follows:

$$\text{LER} = \frac{\text{Yield of intercrop groundnut}}{\text{Yield of sole groundnut}} + \frac{\text{Yield of intercop cassava}}{\text{Yield of sole cassava}} \quad (5)$$

Profitability analysis

Enterprise budgeting technique was used to determine the profitability of the sole cassava, sole groundnut and cassava groundnut intercropping systems.

Total revenue **($SLL \cdot ha^{-1}$):** The total revenue was estimated by multiplying the marketable yield of the harvested crops for each treatment plot by the unit price of the marketable yield at the farm gate.

Total cost of production **($SLL \cdot ha^{-1}$):** The total cost of production for each treatment plot is comprised of the sum of the cost of inputs and labour. The cost of input was determined by multiplying the number of planting materials planted per plot by the unit cost of the planting materials. The cost of labour was determined by multiplying the number of man-days for each activity by the unit cost per man-day.

Gross profit **($SLL \cdot ha^{-1}$):** The gross profit was determined by subtracting the total cost of production from the total revenue.

Benefit-cost ratio **(*BCR*):** The BCR of the various treatments was calculated as the ratio of total revenue over the total cost of production.

Sensitivity analysis

A sensitivity analysis was conducted on the BCR for six scenarios of yield loss in cassava and groundnut (**Table 1**) which may likely occur because of the negative effects of adverse weather events.

2.6. Soil Organic Carbon Stock Measurement

Soil samples were collected from the on-farm trial sites to quantify changes in soil organic carbon stock due to the treatment effect. The change in soil organic carbon stock at the harvest of the groundnut and cassava was monitored against a baseline (after land preparation) of the on-farm trials for the four treatments. The treatments were sole groundnut, sole cassava and cassava-groundnut intercrop. A minimum of three sampling strata (relatively homogenous strata) was identified. Within each homogeneous unit (stratum), at least five soil cores were collected at a depth of 20 cm to form a composite sample using an auger. The composite samples represented the total area of the strata. The composite soil samples were then placed in well-labelled sample bags and transported to the Analytical Services Laboratory of the Njala Agricultural Research Centre (NARC) laboratory for the determination of total carbon content. The soil bulk density was collected using a bulk density kit and separately placed into tightly fitted containers to prevent moisture loss.

The soil samples were transferred into soil sample containers with labels matching those from the field for the determination of soil bulk density and total carbon content.

Soil Bulk Density: The soil bulk density samples collected from the field were immediately weighed to determine the initial weight. They were then oven-dried to constant weight and weighed again. The results obtained were used to calculate the bulk density in $g \cdot cm^{-3}$ [11].

Total Carbon: The soil samples collected were air-dried for three days, crushed and sieved to pass through the <2 mm mesh. Samples of 0.5 g of air-dried (2 mm sieved) soil were placed into a 500 mL conical flask. Potassium dichromate and sulphuric acid were added to digest the organic matter in the samples. Then, 50 mL of deionized water was added and allowed to cool before titrating with ferrous ammonium sulphate [12].

Table 1. Yield loss scenarios for groundnut and cassava for each cropping system.

Yield loss scenarios	Estimated yield loss (%)	
	Groundnut	Cassava
1) Sole groundnut	20	0
2) Sole cassava	0	20
3) Cassava-groundnut intercrop	20	20
4) Sole groundnut	40	0
5) Sole cassava	0	40
6) Cassava-groundnut intercrop	40	40

Soil Organic Carbon stock: The soil organic carbon stork was calculated as follows:

$$\text{SOC stock} = \text{d} \times \text{BD} \times \text{SOC} \times \text{CFst}$$

where:

d = depth of horizon/depth class [m].

BD = bulk density [kg·m^{-3}].

SOC stock = soil organic carbon stock (kg·m^{-2}).

SOC = soil organic carbon constant of <2 mm sieve soil.

CFst = correction factor for stoniness ((1 − % stones)/100), including subtraction of gravel and stones.

The SOC stock in kg·m^2 was converted to kg·ha^{-1} using the following formula;

SOC stock (kg·ha^{-2}) = SOC value (kg·m^{-2}) × 10,000.

The net change in soil organic carbon was determined by the following formula:

$$\Delta\text{SOC} = \text{SOCt}_2 - \text{SOCt}_1$$

where:

ΔSOC = annual change in soil organic carbon stock (kg·ha^{-1}).

SOCt_1 = Soil organic carbon stock before the on-farm trial (kg·ha^{-1}).

SOCt_2 = Soil organic carbon stock at the end of the on-farm trial (kg·ha^{-1}).

2.7. Statistical Analysis

Analysis of variance was conducted to determine the effects of different treatments using a mixed linear model MIXED procedure of SAS [13]. In the mixed model analysis, the treatments were used as fixed factors and "replicate" within on-farm trials were considered as random factors. The effects of the various treatments were compared by computing least square means and standard errors of difference (SED) using the pdiff option in the MIXED procedure. The significance of the difference was evaluated at a 0.05 level of probability.

3. Results and Discussions

3.1. Yield and Yield Components

Groundnut

Intercropping groundnut with cassava had a significant influence ($p < 0.05$) on the aboveground biomass, the average number of filled pods per plant and the fresh pod yield of groundnut in all the locations (**Table 2**). In each location, the highest aboveground biomass, average number of filled pods per plant and fresh pod yield of groundnut were recorded in the sole groundnut cropping system. In comparison to the sole crop, the average aboveground biomass, the average number of filled pods per plant and fresh pod yield of the intercropped groundnut across the locations significantly decreased by 33%, 15% and 31% respectively. Previous studies have reported a decrease in groundnut yield when intercropped with cassava [14]. The decrease in the number of pods per plant

Table 2. Effect of intercropping on the aboveground biomass, average number of pods per plant and fresh pod yield of groundnut.

Variables	Treatments	Location			
		Bai Largor	Bassah	Njala Kanima	Average
Aboveground biomass ($t \cdot ha^{-1}$)	Sole groundnut	9.9	7.1	10.7	9.2
	Cassava-groundnut intercrop	5.6	4.4	8.6	6.2
	F-test (p-value)	0.024	0.0002	0.0379	0.0049
	SED	1.2	0.2	0.7	0.9
Average number of roots per plant	Sole cassava	8.5	7.2	7.7	7.8
	Cassava-groundnut intercrop	7.3	6.4	6.3	6.6
	F-test (p-value)	0.0053	0.0249	0.0019	0.0007
	SED	2.6	0.2	0.2	0.3
Fresh root yield ($t \cdot ha^{-1}$)	Sole cassava	1.6	1.6	1.7	1.6
	Cassava-groundnut intercrop	1.0	1.3	1.0	1.1
	F-test (p-value)	0.0204	<0.0001	0.0091	<0.0001
	SED	0.2	0.0	0.1	0.4

could be attributed to the decrease in biomass. A significant ($p = 0.03$) and positive correlation ($r = 0.51$) were found between the above-ground biomass and the number of pods per plant. The positive correlation indicates that a decrease in the aboveground biomass could lead to a decrease in the number of pods per plant. The low pod yield of groundnut in both the sole and intercrop groundnut could also be attributed to high incidence rosette diseases and the low amount of phosphorus (54.79 to 79.42 $mg \cdot kg^{-1}$) and nitrogen (0.21 to 0.31 $g \cdot kg^{-1}$) at the trial sites.

Cassava

Intercropping cassava with groundnut had no significant influence ($p > 0.05$) on the aboveground biomass, the average number of roots per plant and the fresh root yield of cassava in all the locations (Table 3). However, the sole plots of cassava had the highest aboveground biomass, number of roots per plant and fresh root yield in all the locations. A similar result of no significant difference in the aboveground biomass was found between the treatments of pure cassava and the relative treatments of cassava-groundnut intercrop [15]. The no significant influence on the above groundnut biomass of cassava may be due to the different growth habits of the two crops while cassava has erect growth and groundnut is low growing. Besides, the cassava plants in the intercropping systems were mulched with groundnut residues. This may have contributed to an increase in the total nitrogen in the soil after the decomposition of the groundnut residues thus enhancing the vegetative growth of the cassava plants in the intercropping system to some extent. The previous research findings have shown that groundnut

Table 3. Effect of intercropping on the aboveground biomass, average number of roots per plant and fresh root yield of cassava.

Variables	Treatments	Location			
		Bai Largor	Bassah	Njala Kanima	Average
Aboveground biomass ($t \cdot ha^{-1}$)	Sole cassava	16.1	17.9	22.4	18.8
	Cassava-groundnut intercrop	11.8	14.3	20.9	15.7
	F-test (p-value)	0.0575	0.1491	0.4190	0.1134
	SED	1.6	2.0	1.7	1.9
Average number of roots per plant	Sole cassava	5.3	3.5	4.2	4.4
	Cassava-groundnut intercrop	4.4	3.3	3.9	3.9
	F-test (p-value)	0.1835	0.6185	0.1042	0.1957
	SED	0.6	0.3	0.2	0.4
Fresh root yield ($t \cdot ha^{-1}$)	Sole cassava	20.0	14.8	19.4	18.1
	Cassava-groundnut intercrop	16.0	12.2	16.8	15.0
	F-test (p-value)	0.1246	0.2157	0.3511	0.0607
	SED	2.1	1.7	2.5	1.5

SED: Standard Error of Difference at 0.05 level of probability.

residues have the potential to contribute to total nitrogen stocks if retained in the field [10]. Even though intercropping had no significant influence on the aboveground biomass of cassava, the aboveground biomass for the sole cassava was higher than the intercropped cassava. Average across locations, intercropping cassava with groundnut decreased the aboveground biomass, the average number of roots per plant and fresh root yield of cassava by 17%, 11% and 17% respectively. The decrease could be associated with the competition for plant growth resources during the root initiation stage of the cassava *i.e.* during the first three months after planting. At this stage, the groundnut plants were still in the field and not harvested. Besides, the fresh root yield was significantly and positively correlated with the aboveground biomass ($p = 0.0515$, $r = 0.47$) and the number of roots per plant ($p < 0.0001$, $r = 0.82$). This result shows that higher values of aboveground biomass and number of roots per plant of the sole cassava resultantly led to higher values of fresh root yield obtained from the sole cassava when compared to the intercropped cassava.

3.2. Productivity

Land use efficiency

The land equivalent ratio (LER) was favourable (LER > 1) for the cassava-groundnut intercropping systems in all the locations (Table 4). This result indicates a benefit of using intercropping compared to sole cropping in terms of land use efficiency. Previous studies on cassava groundnut intercropping have

Table 4. Land equivalent ratio for the cassava-groundnut intercropping systems for each location.

Trial site	Cropping system	Yield of groundnut	Yield of Cassava	LER
Bai Largor	Sole groundnut	1003	0	0.61
	Sole cassava	0	20,000	0.80
	Cassava-groundnut intercrop	609	16,000	1.41
Njala Kanima	Sole groundnut	1035	0	0.61
	Sole cassava	0	19,444	0.86
	Cassava-groundnut intercrop	632	16,778	1.47
Bassah	Sole groundnut	1028	0	0.77
	Sole cassava	0	14,778	0.83
	Cassava-groundnut intercrop	790	12,222	1.60
Average	Sole groundnut	1022	0	0.66
	Sole cassava	0	18,074	0.83
	Cassava-groundnut intercrop	677	15,000	1.49

reported similar results of favourable land use efficiency advantage of intercropping over sole cropping in cassava-groundnut-based intercropping systems [16] and [17].

Profitability analysis

Table 5 presents the profitability analysis of the sole cassava, sole groundnut and cassava-groundnut intercropping system for the different locations.

***Total revenue*:** At each location, the cassava groundnut intercrop generated higher revenues when compared to the sole groundnut and sole cassava. In the cassava-groundnut intercrop, cassava accounted for 75% of total revenue even though it had a lower farm gate price (SLL 1300 kg^{-1}) when compared to the groundnut (SLL 6000 kg^{-1}). This shows that the kilograms of cassava sold were more than the groundnut. The revenue generated from the intercrop cassava was also higher than the sole cassava in each location even though the total root yield for the sole cassava was higher than the intercrop cassava. For the profitability analysis, the farmers separated the total yield of the cassava into tradable and non-tradable storage roots based on the root size. The non-tradable roots were not included in the profitability analysis. Average across locations, the tradable root size accounted for 96.4% and 79.9% of the total yield for the intercrop cassava and sole cassava respectively. The high percentage of tradable cassava roots was obtained from the intercropped cassava the cassava roots were relatively bigger than cassava roots of sole cassava. This could be attributed to the enhancement of soil fertility resulting from the decomposition of the groundnut residues that were mulched around the cassava plants of the intercropping system. Results from previous have shown that intercropping cassava with groundnut had a positive effect on the storage root size of cassava [18].

Total cost of production: The total cost of production varies among the sole groundnut, sole cassava and cassava-groundnut intercrop. The highest cost of

Table 5. Profitability analysis, including total benefits, the total cost of production, net benefits and benefit-cost ratio as affected by the cassava groundnut-based cropping systems for each trial site.

Cropping system	Items	Trial Sites			
		Bai Largor	Bassah	Njala Kanima	Average
		SLL·ha^{-1}			
Sole cassava	Total revenue	19,066,667	21,088,889	15,455,556	18,537,037
	Fresh cassava roots	19,066,667	21,088,889	15,455,556	18,537,037
	Total Cost of production	11,270,000	11,270,000	11,270,000	11,270,000
	Cassava cuttings	400,000	400,000	400,000	400,000
	Labour	10,870,000	10,870,000	10,870,000	10,870,000
	Gross profit	7,796,667	9,818,889	4,185,556	7,267,037
	Benefit-cost ratio	1.69	1.87	1.37	1.64
Sole groundnut	Total revenue	9,648,000	9,816,000	9,936,000	9,800,000
	Fresh groundnut pods	9,648,000	9,816,000	9,936,000	9,800,000
	Total Cost of production	11,730,000	11,730,000	11,730,000	11,730,000
	Groundnut seeds	900,000	900,000	900,000	900,000
	Labour	10,830,000	10,830,000	10,830,000	10,830,000
	Gross profit	−2,082,000	−1,914,000	−1,794,000	−1,930,000
	Benefit-cost ratio	0.82	0.84	0.85	0.84
Cassava groundnut intercrop	Total revenue	26,046,222	22,594,222	29,468,000	26,036,148
	Fresh cassava roots	20,222,222	15,022,222	23,400,000	19,548,148
	Fresh groundnut pods	5,824,000	7,572,000	6,068,000	6,488,000
	Total Cost of production	14,000,000	14,000,000	14,000,000	14,000,000
	Cassava cuttings	400,000	400,000	400,000	400,000
	Groundnut seeds	900,000	900,000	900,000	900,000
	Labour	12,700,000	12,700,000	12,700,000	12,700,000
	Gross profit	12,046,222	8,594,222	15,468,000	12,036,148
	Benefit-cost ratio	1.86	1.61	2.10	1.86

Note: Fresh cassava roots were sold at a farm gate price of SLL 1300 per kg; Fresh groundnut pods were sold at a farm gate price of SLL 6000 per kg, 1 bundle of cassava stems (50 stems per bundle 1.4 m long); 1 bag of unshelled groundnut was bought at SLL 300,000 per bag, Labour was rated at SLL 15,000 per man day.

production was obtained from the cassava-groundnut intercropping system, which could be attributed to the combined cost of planting both the cassava and groundnut. The total cost of production for the intercropping system was 16.2% and 19.5% higher than the sole groundnut and sole cassava respectively. The cost of labour for land preparation, planting, weeding and harvesting of groundnut was rated at SLL 15,000 per man-day whilst harvesting of cassava was rated at SLL 20,000 per man-day. The total cost of labour differed for the different operations for each of the cropping systems and accounted for 96.4%, 92.3% and 90.7% of the total cost of production for the sole cassava, sole groundnut and cassava groundnut intercrop respectively.

Gross profit and benefit-cost ratio: The cassava-groundnut intercropping treatment had the highest gross profit and benefit-cost ratio even though it had the highest total cost of production. Even though intercropping cassava with groundnut incurred the highest cost of production per hectare the average benefit-cost ratio across the locations for the cassava groundnut intercrop increased by 123% and 13% when compared to the sole groundnut and sole cassava. This increase could be attributed to the higher revenue generated from the total sale of cassava roots and groundnut pods. However, the results of previous studies revealed that the cassava-groundnut intercropping systems were more profitable than the sole crops of cassava and groundnut [14]. The gross profit and benefit-cost ratios were also favourable for the sole cassava. On the contrary, the gross profit and benefit-cost ratios were however not favourable for the sole groundnut. This could be attributed to the lower revenue obtained from the sole groundnut plots resulting from the low yield of the groundnut which may have been caused by the high incidence of the rosette disease and low amount of phosphorus (54.79 to 79.42 mg·kg^{-1}) and nitrogen (0.21 to 0.31 g·kg^{-1}) at the trial sites.

Sensitivity Analysis

Figure 1 presents a sensitivity analysis of the effect of different scenarios of yield loss in cassava and groundnut on BCR for the sole cassava, sole groundnut and cassava-groundnut intercrop. In the event of adverse weather conditions (seasonal droughts or heavy rainfall which may cause erosion or flooding), which may cause a 40% yield loss in both the cassava and groundnut, the benefit-cost ratio would only be favourable for the cassava groundnut intercropping system. The BCR for the sole cassava could be favourable in the event of a 20% yield loss in cassava whilst the BCR for the sole groundnut was not favourable for none of the yield loss scenarios. This result confirms that the cassava-groundnut intercropping system is a climate-resilient crop production practice for increasing crop productivity within fragile cropping systems that are pruned to the adverse weather events and the insurgence of pests and diseases associated with the negative effects of climate change.

3.3. Changes in Soil Organic Carbon Stock

Table 6 presents the results of the analysis of the SOC stock for the uncropped adjacent site, sole groundnut, sole cassava and cassava groundnut treatments for each trial site location. In comparison to the baseline, the changes in SOC stock for the uncropped adjacent site were favourable at each location. On average

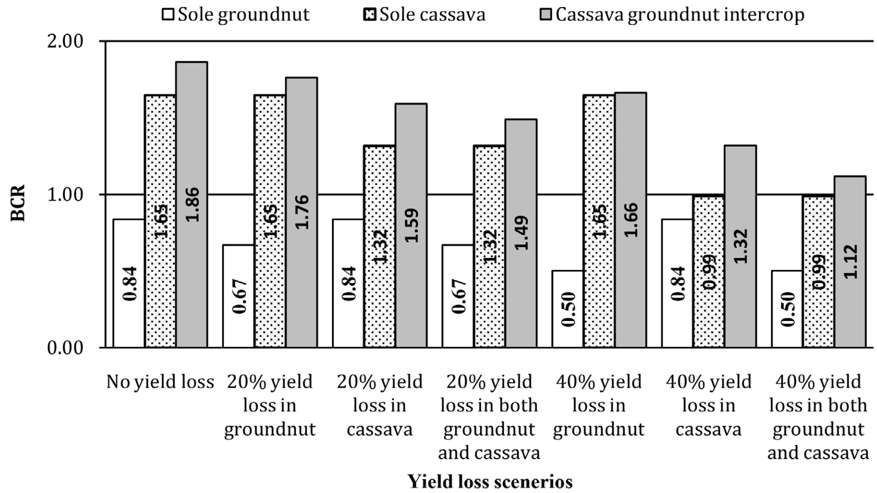

Figure 1. Sensitivity analysis of yield loss scenarios on BCR for the cassava groundnut-based cropping systems.

Table 6. Changes in soil organic carbon stock at harvest of the groundnut and cassava for the uncropped adjacent land, sole groundnut, sole cassava and cassava-groundnut intercrop at each location.

Location/Treatments	Baseline	Harvest of groundnut			Harvest of cassava		
	SOC stock	SOC stock	Net SOC	% change	SOC stock	Net SOC	% change
Bai Largor							
Sole groundnut	18,564	15,120	−3444	−18.6	15,064	−3500	−23.2
Sole cassava	18,564	13,563	−5001	−26.9	12,880	−5684	−44.1
Cassava-groundnut intercrop	18,564	16,647	−1917	−10.3	19,364	800	4.1
Bassah							
Sole groundnut	34,613	25,833	−8779	−25.4	21,613	−13,000	−60.1
Sole cassava	34,613	22,400	−12,213	−35.3	28,812	−5800	−20.1
Cassava-groundnut intercrop	34,613	23,147	−11,466	−33.1	35,510	898	2.5
Njala Kanima							
Sole groundnut	28,100	23,147	−4953	−17.6	22,500	−5599	−24.9
Sole cassava	28,100	23,147	−4953	−17.6	17,200	−10,900	−63.4
Cassava-groundnut intercrop	28,100	21,493	−6606	−23.5	29,299	1200	4.1
Average							
Sole groundnut	27,092	21,367	−5725	−21.1	19,726	−7366	−37.3
Sole cassava	27,092	19,703	−7389	−27.3	19,631	−7461	−38.0
Cassava-groundnut intercrop	27,092	20,429	−6663	−24.6	28,058	966	3.4

across the locations, SOC for the uncropped adjacent site increased by 18.4% and 31.2% at the harvest of the groundnut and cassava respectively. At each location, the changes in the SOC stock for the cassava-groundnut intercrop were only favourable at the harvest of the cassava. This could be attributed to the decomposition of the groundnut residues that were mulched with the intercrop cassava. Average across locations, the SOC stock for the cassava-groundnut intercrop at harvest of the cassava increased by 3.4% when compared to the baseline. Previous research studies have shown that groundnut residues have the potential of increasing SOC if retained in the field, conversely, subsequent removal of the groundnut residues could lead to a sizable loss of SOC from the field [10]. On the contrary, the changes in the SOC stock for the sole cassava and sole groundnut were not favourable at both the harvest of the groundnut and cassava, which shows that conventional tillage practice without residue management, could lead to the loss of SOC in the field [19].

4. Conclusion

In conclusion, the results confirm that cassava-groundnut intercropping is a sustainable land management practice that could increase soil organic carbon stock and enhance crop productivity on smallholder farms. This practice should therefore be promoted to farmers to increase crop productivity and build their resilience to adapt to and mitigate climate change on smallholder farms.

Acknowledgements

This study was undertaken within the framework of the project titled "Sustainable Land Management for Climate Change Adaptation and Mitigation (SLM-4CCAM) in Moyamba, Sierra Leone" funded by the European Union through Expertise France under the supervision of the Economic Community of West African States (ECOWAS). The authors would like to thank all of the farmers who took part in the on-farm trials, ACF Field technicians for data collection and NARC technicians for collecting and analyzing the soil samples.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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